

MEASUREMENT OF GROUNDING SYSTEM RESISTANCE BASED ON GROUND HIGH FREQUENCY BEHAVIOR FOR DIFFERENT SOIL TYPE

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Abstract: Reliable and accurate measurement of Ground Resistance Value (GRV) is utmost important for effective Lightning Protection System (LPS). However, the common and conventional ground resistance measurement using DC current injection provides not the true value of resistance when considering the natural characteristic of lightning current. When the LPS conducting naturally occurring lightning surge to ground, the ground resistance behaves like an impedance. Practically the impedance of the grounding system is much higher than DC ground resistance. Because of that, measuring GRV using DC or fixed frequency current is not highly accurate. This is so because the impedance takes account of the surge high frequency response. This paper describes a new technique that can determine true ground resistance value more accurately in a noisy environment using R-L-C resonance circuit concept.

Key words: measurement, DC, high frequency, lightning, surge, LPS, resonance.

I. INTRODUCTION

Lightning is a natural phenomenon. It is an electrostatic breakdown in the air accompany with thunder. Lightning occurs because the vertical and horizontal moving cloud, which is changing itself to become an electrical-charge cloud. Most of the lightning discharge is ground discharge. The ground discharge account for the damages to the building structure and lightning related hazardous to human being due to direct strike.

For any service's reliability, efficiency and resilient to outages, proper Lightning Protection System (LPS) installations are necessary. The direct and indirect lightning strike to building can be prevented by installing LPS. LPS consists of 2 major types; internal protection and external protection. Both types of LPS need grounding system because they provide means to discharge lightning currents into the

ground. Thus ensuring safety to equipment and personnel from the dangerous ground potential rise (GPR) due lightning discharge in to the ground.

Beside grounding system resistance (GSR), grounding system also has grounding system impedance (GSI) due to transient and impulse current. The impedance of the grounding system consists of real and imaginary value. Where the real value is resistance R and imaginary value is reactance X . However, without accurate measurement of grounding resistance and impedance, the design of LPS can be quite misleading and leading to wrong judgement which can be very fatal either to the designer, contractor or the uses. Besides, without accurate measurement of grounding system as important part of LPS, inspection and maintenance program of grounding system could not be optimized.

II. GROUNDING SYSTEM: PART OF LPS

Generally, the requirement of grounding system resistance (GSR) for LPS is normally less than 5 ohm depends on local condition and standard use in these services. Very low GSR value is important to LPS because it provides means to discharge electric currents into the ground under normal and fault conditions without exceeding any operating and equipment limits[1]. Thus, ensuring safety to equipment and personnel from the dangerous ground potential rise (GPR) due lightning discharge in to the ground. The lower the resistance of grounding system, the better protection it provides [2]. Design, construction, commissioning and maintenance of the grounding system are critical in ensuring reliable, continuous, efficient, and resilient to transient over-voltages in any protected facilities. Proper grounding system is necessary to produce high performance of protection system.

According to the ANSI/IEEE Std.80-1986 [1], in principle, a safe grounding system has two objectives:

1. To provide means to carry electric currents into the earth under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service.
2. To assure that a person in the vicinity of grounded facilities is not exposed to the danger of critical electric shock.

III. INFLUENCES OF IMPULSE CURRENT ON GROUNDING SYSTEM

Under the effect of impulse current, the grounding system can be treated as a distributed lump circuit consisting of inductance, capacitance, resistance and conductance[3]. The impulse current has a high frequency[4]. Figure 1.A shows the current I impinging on the rod electrode and enters the ground, which in addition to its resistivity has a dielectric constant k . Details of grounding system under the impulse current characteristics can be found in [1],[5], and [6]. Thus in parallel to the conductive current in the ground there develops a capacitive current in case the electrode voltage changes with time. Figure 1.B shows equivalent circuit of driven rod under impulse. L is inductance of such a rod, R and C are resistance and capacitance of ground respectively if consider rod has good contact with soil. Because the ground response with the behavior equivalent to an R-L-C circuit, the effects of R-L-C become significant.

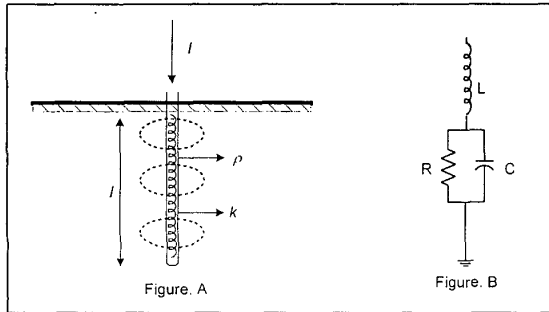


Figure 1. Grounding system due to Impulse current and equivalent circuit

$$C = \frac{k.l}{2 \cdot \log_e \left[\frac{2.l}{a} \right]} \cdot \frac{10^{-9}}{9} \text{ Farad}$$

Resistance and inductance elements are attributed to the grounding system metallic material in the shape of cylindrical, rectangular, and circular bar or tape. Usually the ground conductors are of copper or aluminum. When current discharge to the ground, the changing lines of flux inside the

conductors also contribute to the induced voltage of the circuit and therefore to the inductance[7].

$$L = 2.l \cdot \log_e \left[\frac{2.l}{a} \right] \cdot 10^{-7} \text{ Henry}$$

IV. RESONANCE

A circuit is said to be resonance when the applied voltage ∇ and the resulting current \bar{I} are in phase [8]. Thus at resonance, the equivalent complex impedance of the circuit consists of only resistance R , the current is at maximum. The R-L-C circuit shown in Figure.2 below, has a complex impedance

$$Z = R + j(X_L - X_C) \quad (1)$$

Where;

$$X_L = \omega L \quad (2)$$

and,

$$X_C = \frac{1}{\omega C} \quad (3)$$

The complex impedance will be

$$Z = R + j\left(\omega L - \frac{1}{\omega C}\right) \quad (4)$$

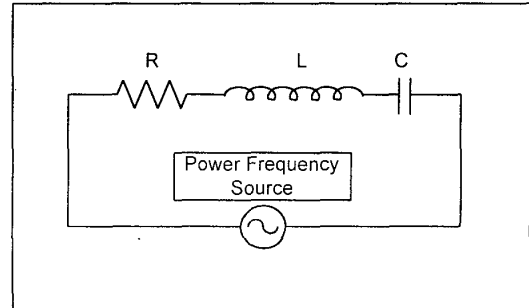


Figure 2 R-L-C series circuit

The circuit is in resonance when

$$X_L = X_C \quad (5)$$

or,

$$\omega L = \frac{1}{\omega C} \quad (6)$$

Then since

$$\omega = 2 \pi f \quad (7)$$

Frequency at resonant is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \text{ Hz} \quad (8)$$

V. DC POLARIZATION

Up to date, most grounding system resistance is measured under direct current (DC) or using power fixed frequency. If DC currents are used, then there is neither capacitive nor inductive coupling. But injecting DC pose another problem, i.e: polarization is liable to occur which tends to give a false reading [11]. These polarization potentials are DC voltages that mask the measured voltage difference. Details of polarization discussion can be found in [9] and [10]. However, the common and conventional ground resistance measurement using DC current injection provides not the true value of resistance when considering the natural characteristic of lightning current. When the LPS conducting naturally occurring lightning surge to ground, the ground resistance behaves like an impedance. Practically the impedance of the grounding system is much higher than DC ground resistance. Because of that, measuring GRV using DC or fixed frequency current is not highly accurate. This is so because the impedance takes account of the surge high frequency response.

VI. THE PROPOSED METHOD

The basic principle of operation of this method consists of a current injection unit (CIU) injecting a controlled variable frequency electric current between two points (on the ground), the ground electrode under test and the unit current probe. Since the ground is treated as a R-L-C ladder network, while the current is of high frequency source, therefore there will be a time when at a particular set of frequency, the input current is at maximum value i.e at resonance.

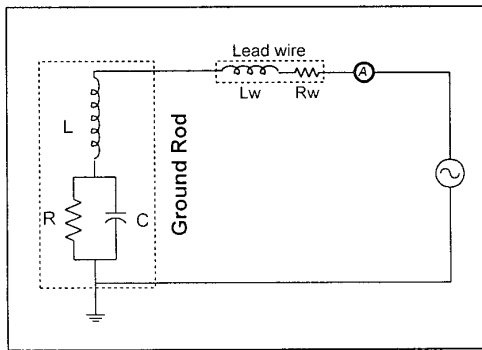


Fig 3. A simple equivalent of grounding system circuit

Its basic principle of operation based on improved Fall-of-Potential method i.e: by injecting a computer controlled variable frequency electric current between two points, the ground electrode under test and the current probe. Figure 3 shows an equivalent circuit when controlled frequency current is injected into the ground [12], [13].

If the frequency of the injected current of a value as such $X_L = X_C$, i.e $X = 0$, the circuit is in resonant where $\omega L = 1/\omega C$. The impedance of the circuit equals the ohmic resistance R . The current is maximum. It is limited by value of R only.

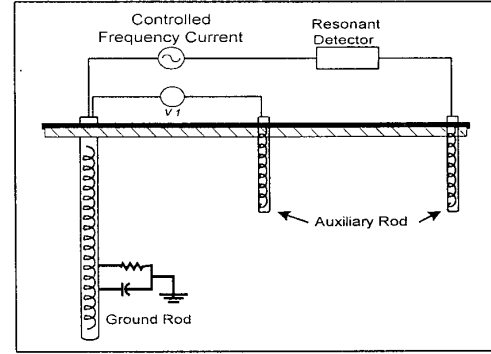


Fig 4. Field measurement arrangement, based on modified Fall-of- Potential method

If the impedance of lead wire is neglected, the output impedance of the measuring system in Figure 3 is:

$$Z(\omega_0) = \frac{R}{1 + (\omega CR)^2} + j \left(\omega L - \frac{\omega CR^2}{1 + (\omega CR)^2} \right) \quad (9)$$

At resonant frequency ω_0 , the complex number j is zero, the equation (1) will be:

$$Z(\omega_0) = \frac{R}{1 + (\omega CR)^2} \quad (10)$$

Because the value of ground capacitance is very small (from nano farad up to pico farad, so $(\omega CR)^2$ considered is zero, the equation (2) will be:

$$Z(\omega_0) = R \quad (11)$$

With determination of inter-probe voltage V_1 and input current I of the measuring system as in figure 4, thus ground resistance R_g at resonance can be found.

VII. RESULT

An electrode with 1-m length and 16 mm diameter was used as the ground electrode. Field measurement was established in two sites. In Electrical Engineering Faculty of UTM (FKE-UTM) which the soil type is clay, and in Kangkar Pulai housing complex area, Johor Bahru, which the soil type is sandy peat soil type.

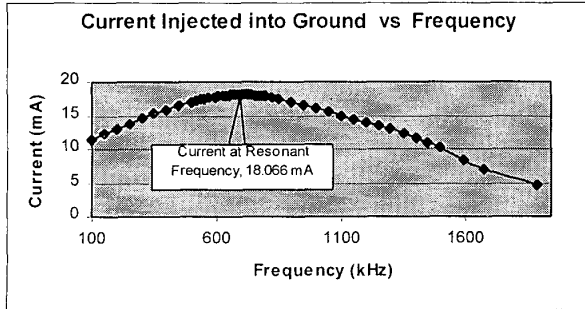


Figure 5. Frequency adjustment against current injection, (Location: FKE-UTM)

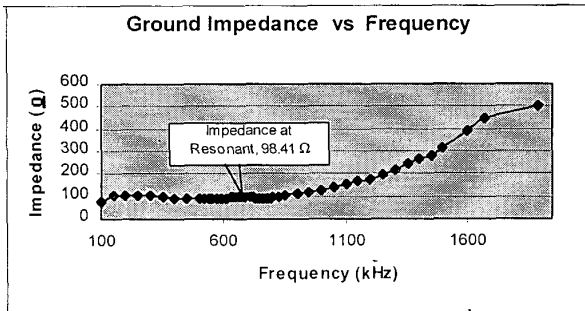


Figure 6. Frequency adjustment against ground impedance (Location: FKE-UTM)

The results of the measurement in FKE-UTM area are shown in Figure 5 and 6. The experiment frequency range is between 100 kHz up to 1.950 MHz. Figure 5 shows the relationship between injected current in to the ground with different frequencies. At 705 kHz correspondence to the current maximum 18,066 mA. Figure 6 shows the ground impedance variation at different frequencies. At resonant frequency, ground resistance R is 98,41Ω.

The results of the measurement in Kangkar Pulai are shown in Figure 7 and 8. The experiment frequency range is between 59 kHz up to 1.950 MHz. Figure 7 shows the relationship between injected current in to the ground with different frequencies. At 810 kHz correspondence to the current maximum 22.76 mA. Figure 8 shows the ground impedance

variation at different frequencies. At resonant frequency, ground resistance R is 126.97Ω.

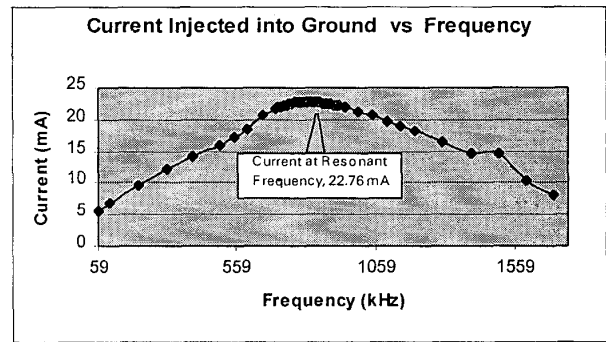


Figure 7. Frequency adjustment against current injection, (Location: Kangkar Pulai)

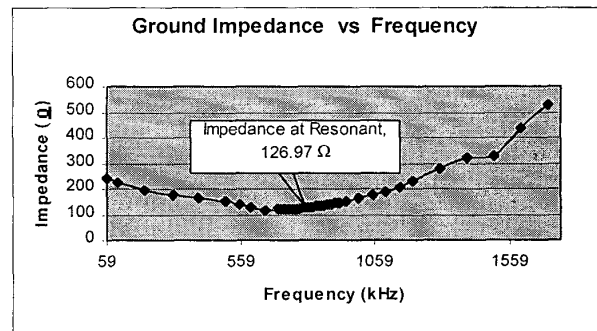


Figure 8. Frequency adjustment against ground impedance (Location: Kangkar Pulai)

VI. CONCLUSIONS

Measurement of grounding system resistance and impedance based on ground high frequency and combination with resonant method has been performed at two sites. The proposed system not only overcome the problem of polarization in soil. It can provide more accurate ground resistance measurement. For different soil type, the frequency of resonant is different for similar grounding system.

VII. ACKNOWLEDGEMENT

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IX. BIOGRAPHIES

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